MATHEMATICAL MODELLING IN STEM EDUCATION: A MATH TRAIL USING LABSTAR™

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Abstract. *Regarding the current scene of STEM education, an effective discipline integration is a need. According to STEM: Integrated teaching framework, teachers use discipline specific methods for discipline integration. Mathematical modelling allows teachers to design integrated STEM activities, with a focus on mathematics discipline. In this paper we developed a math trail with mathematical modelling tasks at major historical venues of Istanbul. Students will collect and analyze data using LabStar™. We reported expert opinions about the tasks included in the math trail and prepared the final tasks for implementation.*

Key words: Mathematical modelling, math trails, outdoor education, STEM integrated teaching framework.

INTRODUCTION

The problems faced by society have altered as the pace of change in technology and science is accelerating. Problems that people face in today's ever-changing world are more multidisciplinary and their solution are required the integration of multiple STEM concepts (Wang, Moore, Roehring & Park, 2011). These problems and solution strategies that require STEM knowledge led the global recognition of the growing importance of STEM education for K-12 level that making students better problem solvers, innovators, logical thinkers, and technologically literate (Morrison, 2006).

Regarding the current scene of STEM education, an effective discipline integration is a need. "STEM education includes the knowledge, skills and beliefs that are collaboratively constructed at the intersection of more than one STEM subject area" (Corlu, Capraro, & Capraro, 2014). For K-12 educators, relating the disciplines with each other is still a major challenge. In literature, several approaches from disciplinary through to transdisciplinary are discussed for STEM Integration (e.g., Burke et al., 2014; Honey et al., 2014; Moore and Smith, 2014; Rennie et al., 2012; Vasquez, 2014/2015; Vasquez et al., 2013). However, teachers need general structures to guide them through discipline integration by applying STEM lesson plans with their students (English, 2016).

STEM Integrated teaching framework, in this regard, offers a methodological integration across disciplines. To employ methodological integration teachers, integrate discipline relevant methods such as project-based learning, scientific inquiry and mathematical modelling to teach other disciplines. For the STEM areas, integrated teaching framework relates scientific inquiry with science, computational thinking with technology, project-based learning with engineering and mathematical modelling with mathematics (Aşık, Doğança-Küçük, Helvacı, & Corlu, 2017; Corlu, 2017). Using these methods for discipline integration allows teachers to teach their main disciplines without losing its unique characteristics, depth, and rigor (National Research Council, 2011).

Mathematics is seen as difficult to integrate into a STEM lesson plan. Teachers usually use mathematics as a tool or as an algorithmic way if required to relate mathematics to other STEM disciplines (Wang, 2012). However, as in other STEM disciplines mathematics is

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equally important to be integrated in a rigorous way to STEM lesson plans. Shaughnessy (2013), in a similar manner, indicated that mathematics in STEM should be made “transparent and explicit”. To guide teachers by integrating mathematics into their STEM lesson plans mathematical modelling in STEM integrated teaching framework comes forth.

Mathematical modelling is about translating real world phenomena into the language of mathematics. The mathematical modelling starts from a situation in real world, evolves into a real model and mathematical model respectively (Blum, 1993). Besides facilitating educators integrate mathematics into other STEM disciplines, mathematical modelling also provides more meaning to the mathematics teaching-learning activities (Blum, 1993). In Turkish context, within the new paradigm of mathematics curriculum, there is also emphasis on deep and rigorous learning by focusing on complex skills such as mathematical reasoning, problem solving and the ability to use mathematics in daily life (Ayas, Corlu, & Aydın, 2013). Mathematical modeling, in this sense, offers methods that teachers can design activities to develop their students’ complex skills.

A mathematical model allows to relate quantities in physical, social and everyday life using mathematical and statistical methods. Within mathematical modelling tasks technology is an essential facilitator to test various assumptions, explore consequences and compare predictions with data (Common Core State Standards Initiative, 2020). In Encyclopedia of Mathematics Education, mathematical modelling competency is defined as solving real-world problems using mathematics (Kaiser, 2014). These skills constitute identifying relevant questions, variables, relations or assumptions in a real-world situation, mathematizing of the situation and interpreting and validating of the solution (Ludwig & Xu, 2010).

In order to design an integrated STEM activity with rigorous mathematics we propose a math trail that cover mathematical modelling tasks where participants use an innovative just-in time data logging device LabStar™ for data collection and analysis.

DESCRIPTION OF THE MATH TRAIL

The math trail we designed covers selected historical places in İstanbul, a metropolitan city of Turkey. In each point at the math trail we developed mathematical modelling tasks for the students. For the math trail LabStar™ data logging device for doing just-in time measurements.

LabStar™: Just-in time data logging device

LabStar™ is a data collection device which collects continuous data through its sensors, namely, distance, ambient temperature, ambient humidity, air pressure, altitude, ambient light, acceleration, and sound intensity. Students can collect data anywhere about different variables, in line with the curriculum and teachers’ learning objectives. Besides data collection, LabStar ™ also enables students and teachers to represent, trim, analyze and interpret the data they collected via LabStar ™ mobile application. Students can proceed to analysis, examine the descriptive statistics, plot line of best fit and conduct bivariate analyses. These analyses create opportunities for teachers and students to describe data, discuss on graphical representations of data and create meaningful associations between representations and real-life situations. Collecting scientific data from real life and analyzing data by engaging in basic statistics also creates opportunities for interdisciplinary learning in STEM education contexts.

Historical Places of Istanbul Math Trail

The content and the activities of the math trail focus on mathematical modeling, data collection and analysis, by investigating phenomena about the scientific concepts such as light, altitude and pressure. Below are the target outcomes related with the main and other disciplines of STEM.

Mathematics: Formulate questions and collect, organize, and display relevant data to answer these questions (NCTM, p. 4); Analyze data, making inferences and predictions based on data, and understanding and using the basic concepts of probability (NCTM, p. 4), Investigate patterns of association in bivariate data (CCSSM) -Grade 8-, Make inferences and justify conclusions from sample surveys, experiments and observational studies (CCSSM) –High School-

Science: Process skills for inquiry: observing, explaining (hypothesizing), predicting, raising questions, planning, and conducting investigations, interpreting evidence, communicating (Harlen, 2000).

Technology: Use technology appropriately in gathering and interpreting data, Demonstrate the ways information acquisition and use technology applications to facilitate evaluation of work, both process and product

Tasks of the Math Trail

Task 1. Towers of İstanbul: Galata and Maiden Towers

1. Task basic data

Definition of task: Galata and Maiden Towers are two towers that watch over İstanbul. Maiden's Tower is located at sea level. However, Galata Tower is located above sea level. Your task is to investigate air pressure with respect to different altitudes and heights of Galata and Maiden Towers.

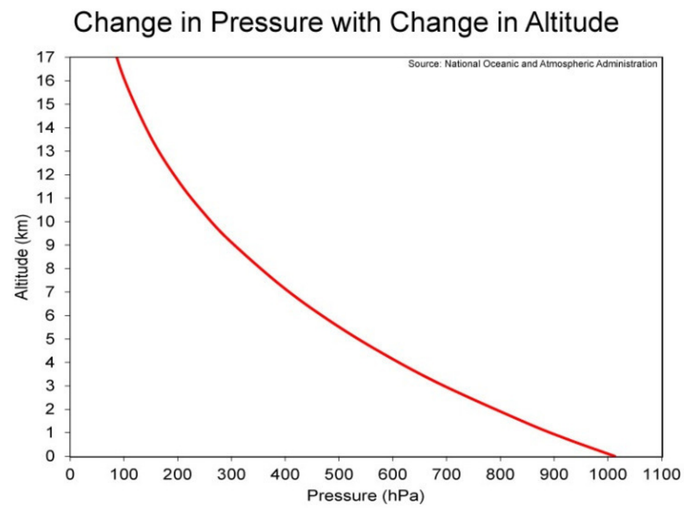
Position: **Galata Tower:** 41°1′32″ and 28°58′27″; Maiden Tower: 41°01′16.2″ and 29°00′15.3″

2. Stepped hints

Hint 1. The atmospheric pressure at a certain location is related with the altitude and the temperature of the place. Measure the atmospheric pressure at different points of tower with LabStar.

Hint 2. How does the atmospheric pressure of Maiden's Tower change in different points at different heights of the tower? (e.g. entrance, top balcony). Is it possible to develop a mathematical model that relates altitude with atmospheric pressure?

Hint 3. Does the atmospheric pressure change at different times of the day? How can you design an experiment to find the answer using LabStar?



Hint 4. How can you design an experiment to test your model in Galata Tower? Is it possible to use the same model for estimating the atmospheric pressure at the top balcony of Galata Tower?

Hint 5. Using below graph for the pressure and altitude, how can you find the altitude of the Galata tower from the sea level? How can you design an experiment to find the answer using LabStar?

About places

Galata Tower: It is one of the oldest towers in the world. It was built by the Byzantine Emperor Anastasius in 528 as the Lighthouse. Its height from the ground to the end of its roof is 66.90 meters. Its weight is about 10,000 tons and its thick body is made of rubble stone. *Maiden's Tower:* The tower, which has a historical past dating back to 24 BC, was built on a small island where the Black Sea meets Marmara Sea. According to the rumor, it was named Maiden's Tower because the emperor imprisoned his daughter in the tower to protect his daughter, who was said to be killed by oracle due to the snakes.

From Grade: 7; *Tools:* LabStar, Paper-Pencil, Smartphone; *Tags:* Mathematics education, data analysis, statistics, altitude, atmospheric pressure

Task 2. The disctrict of tolerance: Balat

1. Task basic data

Definition of task: Like all districts of İstanbul, Balat also hosts many people of different religions and ethnicities. It contains many synagogues, mosques, and churches within itself. Each architectural building reflects their own cultural and aesthetic values of society. So, all differs from each other with their features. A researcher suggests such a hypothesis after visiting and observing different kind of architectural building that serve as worship places in Balat: -Churches are less bright than mosques and synagogues.

Please help him test his hypothesis by gathering data from Ahrida Sinagogue, Yavuz Sultan Selim Mosque and St. George's Cathedral respectively and analyzing it.

Position: Ahrida Sinagogue: 41.03278° and 28.94556°, Yavuz Sultan Selim Mosque: 41°01′35.6″ and 28°57′4.8″, St. George's Cathedral: 41°01′45″ and 28°57′07″

2. Stepped hints

Hint 1. To test his hypothesis, you need gather data related to amount of light. How would you design an inquiry to test the hypothesis? Are there any critical points while gathering data from each place? Please discuss which points are critical/where you should make your measurements when gathering data (position of LabStar, light etc.) to compare data from different places and write them in group notebook. After defining critical points, please measure the amount of light of synagogue, mosque, and cathedral, respectively.

Hint 2. Examine the data. How do you decide typical value representing the related data? Why? (mean, mode, median)

Hint 3. How can you compare the amount of light? Which statistics should you use? (mean, mode, median, or another statistical tests?)

3. About places

Ahrida Sinagogue: The synagogue, built in the early 15th century and named after the city of Ohrid, located in North Macedonia, where its founders migrated to Istanbul, is today the largest capacity synagogue in Istanbul. *Yavuz Sultan Selim Mosque:* The Yavuz Selim Mosque, is a 16th-century Ottoman imperial mosque located at the top of the 5th Hill of Istanbul. It was built on the hill closest to the Golden Horn. Its size and geographic position make it a familiar landmark on the Istanbul skyline. *St. George's Cathedral:* This church, which is connected to the Fener Greek Patriarchate of Istanbul, has been the center of Orthodoxy since the 6th century. It is the main church of most of today's Orthodox churches. The Greek Orthodox Patriarchate is located in the garden of this church, which was built in 1836.

From Grade: 7; *Tools:* LabStar, Paper-Pencil, Smartphone; *Tags:* Mathematics education, data analysis, statistics, light

Task 3. Basilica Cistern

1. Task basic data

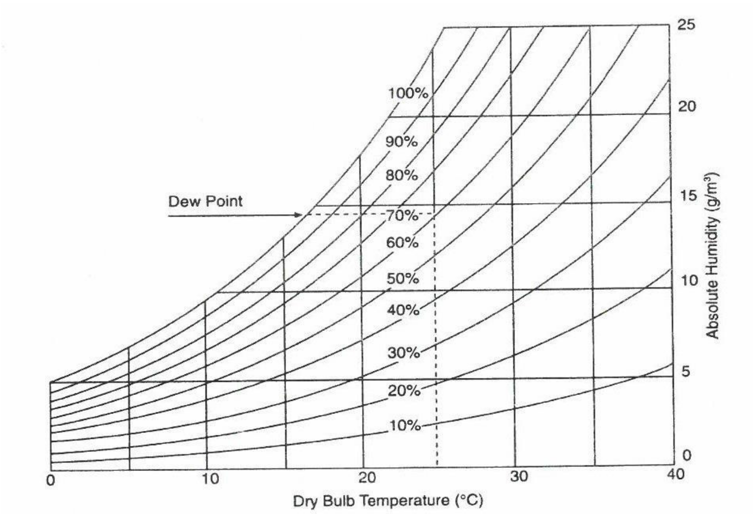
Definition of task: Basilica Cistern was used as a big underground reservoir in Byzantine and Ottoman periods. It is a very humid place to visit. Asthma patients can have a hard time to visit the Cistern for longer periods of time. Therefore, please calculate the amount of moisture in unit dry air in the cistern, in order to give information for the visitors of health risk groups. After your measurements you should decide whether the Cistern is safe for asthma patients in terms of moisture by comparing your data with scientific information from the studies about the amount of the moisture in closed areas and asthma patients.

Position: **41° 0´ 30.2004" and 28° 58´ 40.2060"**

2. Stepped hints

Hint 1. The amount of moisture in dry air is related to relative humidity and the temperature of the place. Measure the relative humidity and temperature with LabStar.

Hint 2. Using the graph below how can you find the amount of moisture in unit dry air (absolute humidity)?



Hint 3. Does the amount of moisture in unit dry air change in different points of the cistern? How can you design an investigation using LabStar to collect data about the amount of moisture in the air at different points in the cistern?

Hint 4. Does the amount of moisture in unit dry air change at different times of the day? How can you design an experiment to find the answer using LabStar?

3. Task meta-data

About this place: The cistern is 140 m long, and 70 m wide, and covers a rectangular area as a giant structure. Accessible with 52-step staircase, the Cistern shelters 336 columns, each of which is 9 m high. Erected at 4.80 m intervals from one another the columns are composed of 12 rows, each has 28 columns.

From Grade: 7; *Tools:* LabStar, Paper-Pencil, Smartphone; *Tags:* Mathematics education, data analysis, statistics, temperature, humidity.

Expert opinion about the Math Trail Tasks

Before implementing the math trail with the students, we took expert opinions from mathematics and science educators about the feasibility of the activities and their recommendations. Two mathematics and one science teachers, who have teaching experience above 15 years gave their opinions using the short evaluation form for each task. The form consisted of the questions below:

- Q1. How would you evaluate the age and grade level appropriateness of the task? (rating scale out of five points)
- Q2. Is the task appropriate for the development of students' mathematical modelling skills? (rating scale out of five points)
- Q3. Is the task clearly defined for teachers and students follow easily? (rating scale out of five points)
- Q4. What are your general opinions and suggestions about the task? (open-ended)

The responses of first three questions of each expert is presented in Table 1.

	Task1			Task 2			Task 3		
	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3
Expert 1 (Mathematics Educator)	4	3	4	5	4	4	4	4	4
Expert 2 (Mathematics Educator)	4	4	4	5	4	5	4	5	4
Expert 3 (Science Educator)	5	5	4	5	5	4	5	5	4

Table 1: Expert Opinion about the Math Trail Tasks.

Table 1 shows that the experts found the tasks appropriate for the designated grade level. They made some recommendations about the science concepts to make the tasks more matched with the science curriculum objectives. For the development of mathematical modelling skills all experts revealed positive opinions. They found the tasks relevant for mathematical modelling skills and made some recommendations for the stepped hints to be more helpful by guiding the students make measurements and interpret data. The legibility of the tasks is evaluated as sufficient by all of the experts.

The answers for the open-ended question included recommendations for the tasks are focused on giving more detailed hints to students to help them pursue the task and make accurate measurements. The tasks were revised according to the suggestions of the experts.

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